A COMPARISON OF TWO REDEVELOPING TEXAS LOWS, JANUARY 1958

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1. INTRODUCTION

It is of interest to examine the similarities and differences in the cyclonic development of two storms that produced extensive rain or snow over the Southern and Eastern States, followed by freezes along the Gulf coast and over Florida during January 1958. This paper discusses the significant and noticeable features of the path, intensity, and weather of the storms through their cycle of development.

These two Lows appeared first in the zone outlined by Bowie and Weightman [1] as the region of origin for Texas type storms and met the other initial condition for Texas storms, namely: high pressure over the Eastern and Northwestern States. Texas storms follow a course toward the northeast or east over the Gulf States then northeastward along the Atlantic seaboard. Although figure 1 shows that the Lows of this study followed generally a normal track, a more critical look at the progress of these Lows shows that they posed entirely different problems for the forecaster.

To avoid subjective opinions about the relative depths or strengths of the storms, a quantitative measure is used to evaluate the strength of the two Lows as they are discussed here. The intensity is evaluated according to the number of standard deviations that the central pressure departs from the mean central pressure of many other Lows at the same latitude. James [2] proposed this as an appropriate statistical measure of the intensity of low and high pressure systems.

For convenience in distinguishing the two Lows in this paper, the earlier one that was first analyzed as a closed center on January 5 will be referred to as Storm A and the later one on January 12 as Storm B.

2. ANTECEDENT CONDITIONS

SURFACE

The two storms formed less than 150 miles apart. Storm A, which started to organize on January 5 about 120 miles south of Brownsville, Tex., would be classed as a center of weak intensity. Its central pressure of 1015 mb. was more than two standard deviations above the normal central pressure for Lows at that latitude. Storm B, which formed a week later, on January 12, about 40 miles northwest of Brownsville, would be classed as a Low of normal intensity. Its central pressure of 1007 mb. was within one standard deviation of normal.

As these storms took shape, certain features of the suface synoptic charts were strikingly similar. Storm A, the least intense in its early stages, was related to a 1044-mb. high cell moving southeastward over the eastern States, a 1042-mb. quasi-stationary High over the Northwest and to an active 980-mb. Low moving eastward across Hudson Bay with a trough extending to the southwest over central Canada and the Plains States. Storm B, which was of normal intensity in the beginning, was associated with almost identical pressure features with respect to position. There was a 1033-mb. High moving southeastward over the Eastern States, a 1026-mb. quasi-stationary High over the Northwestern States, and a 993-mb. Low crossing Hudson Bay. A significant point here is the fact that Storm B, though classed as more intense, was actually associated with less circulation and vorticity than Storm A, inasmuch as the accompanying

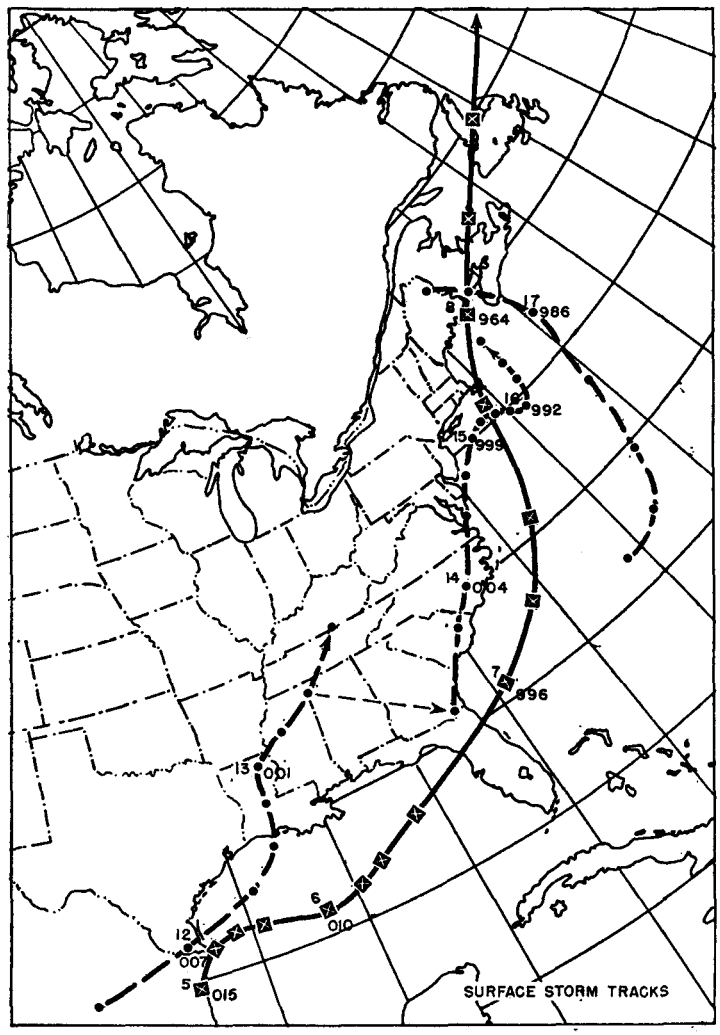

FIGURE 1.—Tracks of storm A, January 5–8, and storm B, January 12–16, 1958.

pressure systems were each roughly 10 mb. less intense than those with Storm A, and this is within the range of one standard deviation for all latitudes. This may be the first anticipation of modification in developments.

There were other dissimilar features. With the beginning of Storm A, a very intense quasi-stationary Low was in the Bering Sea and a second Low was centered about 10° of latitude south of ship station Papa (50° N., 145° W.), resulting in strong southerly flow over the eastern Pacific that maintained or had a tendency to increase the High over the Northwest. Associated with Storm B was a small, diminishing Low in the Pacific about 200 miles southwest of Annette Island with a frontal system extending to the south and a large deep Low dominant in the central North Pacific, about latitude 45° N., moving rapidly eastward. The southerly flow along the Pacific coast was not as strong in this situation with the main Low farther west and there was a tendency for the High over the Northwest to lessen. In the immediate vicinity of Storm B there was a weak Low and associated cold front to the northwest near Midland, Tex., while Storm A had strong northeasterly gradient to the west of it and a small ridge pushing down from the large High area farther to the north.

Both storms moved northeastward from the Texas coast. Storm A continued on to the east but Storm B swung more northerly over Louisiana, then east across Mississippi, Alabama, and Georgia. Both storms redeveloped as they approached the Atlantic coast, Storm A insignificantly near Jacksonville, Fla., and Storm B noticeably in the vicinity of Charleston, S. C.

As the two storms moved across the Gulf of Mexico and the Gulf States, they were accompanied by general rains and gusty winds to the north of the path of the Low. This would not be considered weather closely associated with fronts; however, the developments of the frontal waves were important.

Storm A produced heavy rains totalling 6 inches or more over the lower Rio Grande Valley and the Coastal Bend and widespread snow in amounts up to 7 inches over western Texas, the Panhandle, and eastern New Mexico. Corpus Christi had 7.72 inches of rain January 4–5, with considerable flooding and damage from high winds. Gusts as high as 70 knots were reported in the Corpus Christi area and the highest tide, 4.9 feet MLW, at Navigation Barge Bridge, was the highest since 1933. Heavy rains and gales accompanied Storm A near its center as it crossed the Gulf. Storm B caused moderate to heavy rains over southern Arkansas, Louisiana, and Mississippi, with gusty winds to about 35 knots. During the period prior to redevelopment, the storms caused widespread but generally light amounts of rain in the Southeastern States.

As Storms A and B moved eastward, the Hudson Bay Lows moved rapidly eastward with their troughs more or less stationary along the St. Lawrence River Valley. The Highs over the Eastern States traveled out over the Atlantic to a position directly ahead of the two storms. The High with Storm A moved on east and did not block the path of the storm. However, the High ahead of Storm B ridged back to the northwest to join a High moving down over central Canada. This was the beginning of blocking conditions, similar to those in the second case described by Austin [3], which made the major difference in later development of these two storms. The western High with Storm A remained stationary, but the western High with Storm B dissipated rapidly ahead of the frontolyzing occlusion that moved in from the Pacific. A ridge from the eastern Pacific High immediately built over the Northwest but it was not the same type of persistent High that remained with Storm A, and the remnants of the trough associated with the occlusion later became the flat, weak trough along the west Texas border.

UPPER AIR

The 500-mb. analyses which characterize the upper level conditions associated with the early development of these storms help point out similarities and differences. On January 5, there was a low center just east of Nantucket with a trough to the southwest roughly parallel to the Atlantic coast line. A vast High centered just northwest of San Francisco ridged to the north along the Pacific coast so that most of the United States was in a general northwesterly flow from the west coast ridge to the east coast trough with a small ridge over the east central United States and a minor trough from the Midwest to a low center 200 miles south of Phoenix, Ariz.

Along with Storm B there was a similar progression, a trough along the Atlantic coast, and a ridge over the Central States separated by a trough from a western ridge—but the magnitude of these features was noticeably different. The two ridges were nearly equal in intensity but the western ridge was over the Rocky Mountains and southern California with a trough off the Pacific coast. This shorter distance between ridges made the midwestern trough much sharper as it extended to a low center just north of Midland, Tex. The trough off the Atlantic coast with Storm B was orientated more north-south from a Low over Nova Scotia.

The Lows in the Southwest were the most closely associated upper-level features of these two storms. The Low over Midland, with Storm B, was well to the east of Storm A's Phoenix Low, and although the area of closed circulation about the Midland Low was smaller, its central height was about 150 feet lower than that of the Phoenix Low.

As Storm A moved eastward the trough over the Midwest moved to the western Great Lakes and a new Low formed over Lake Superior indicating deepening. The flow from this trough eastward became more westerly and the minor ridge between the two troughs became very weak. A small, secondary Low broke off from the Phoenix Low and moved to a position in line with the deepening trough in the middle of the United States. The cyclonic vorticity with this deepening trough was in a good position for deepening of the secondary Low, and

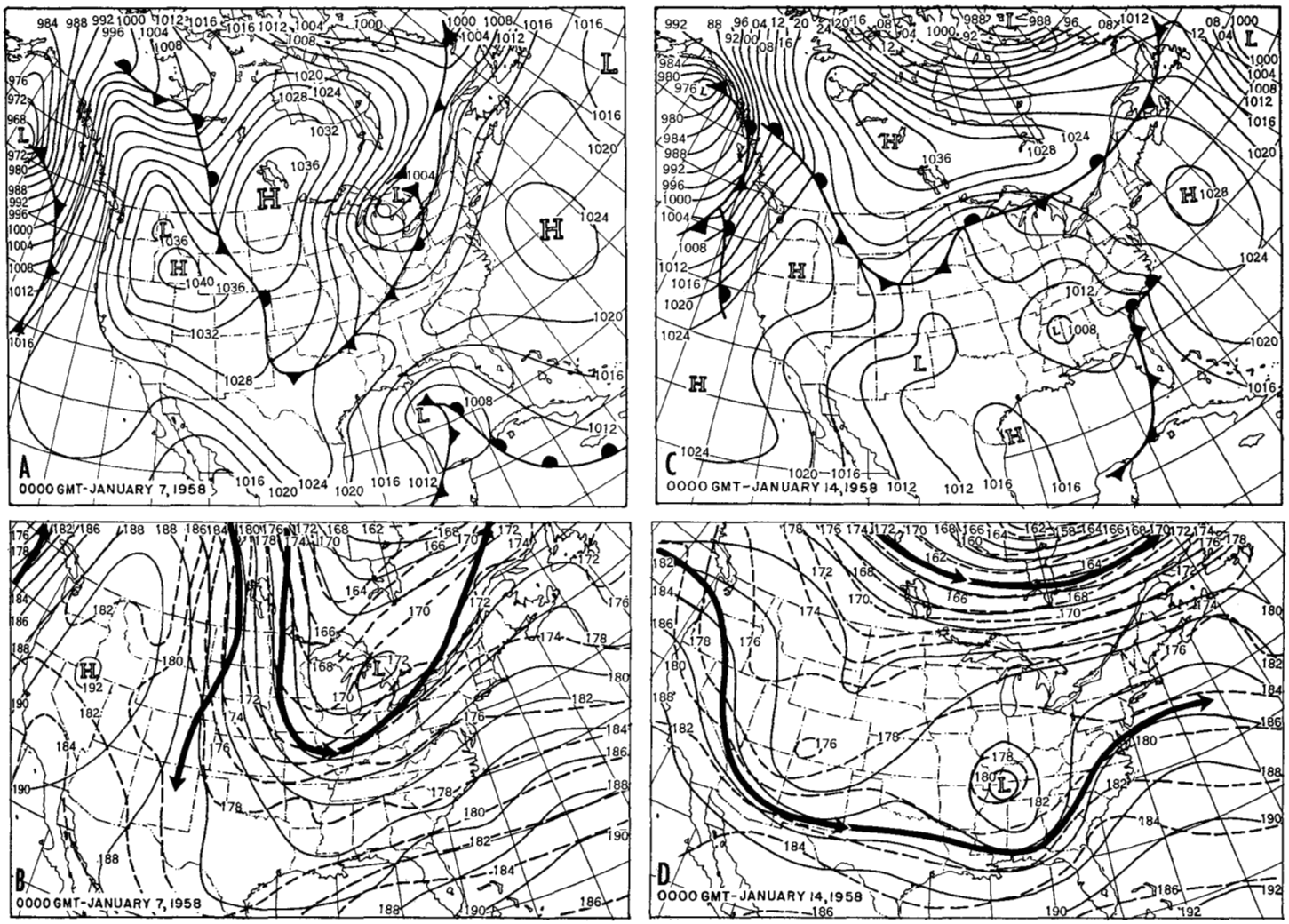

FIGURE 2.—Sea level synoptic charts (A) and (C) for 0000 GMT January 7 and 14, 1958, respectively, and the corresponding 500-mb. charts (B) and (D), with 1000-500-mb, thickness lines (dashed) and 300-mb. jets.

this is an important feature in the difference in development of these two storms.

With Storm B the western ridge became less important and the cyclonic vorticity along the western side of the trough over the central United States was negligible. The Midland Low moved eastward with cyclonic vorticity south of its center, but an objective analysis would quickly show that there was less vorticity available for surface development with this later storm. The east coast ridge remained more pronounced, but there were no strong indications of blocking action.

The 300-mb. maximum wind axes are superimposed on the 500-mb. charts to represent the upper-level jets. The main jet with Storm A entered the United States in the far Northwest, crossed Canada and dipped into the Plains States, then crossed the central Appalachians and curved east toward Bermuda. The jet with Storm B ridged across Washington State, dipped south to near Tucson, then swung east across the Southern States and ridged along the middle Atlantic coast.

3. COMPARISON OF THE STORMS

FIRST DAY FEATURES

At 0000 GMT January 7 (fig. 2A), Storm A was centered about 120 miles south of Burrwood, La.; however, there were indications that a new Low was forming southwest of Tampa, Fla. The weak to moderate wave in the Gulf of Mexico associated with this Low produced overrunning rain as far north as Atlanta, Ga. During this time, at 500 mb. (fig. 2B), a small Low was centered near Sault Sainte Marie, with a trough to the southwest over the Midwest, Mississippi, Louisiana, and coastal Texas. A weak cyclonic vorticity maximum associated with Storm A was centered over Mississippi. A second cyclonic vorticity maximum, the remnant of the Phoenix Low, was just south of Bryan, Tex. A strong southwesterly flow ahead of the trough extended from the Gulf along the Atlantic coast to the Maritime Provinces. A strong, deep northerly flow that extended from the Northwest Territories to Texas was advecting cold air down into the trough and developing favorable conditions for surface deepening.

Other surface features with Storm A were: a very slowly diminishing high pressure cell east of Cape Hatteras, that had moved east from the mid-Atlantic coast; a sharp trough, with an associated cold front, from southern Greenland to a low center over the eastern Great Lakes, then southwest over the east-central United States; and

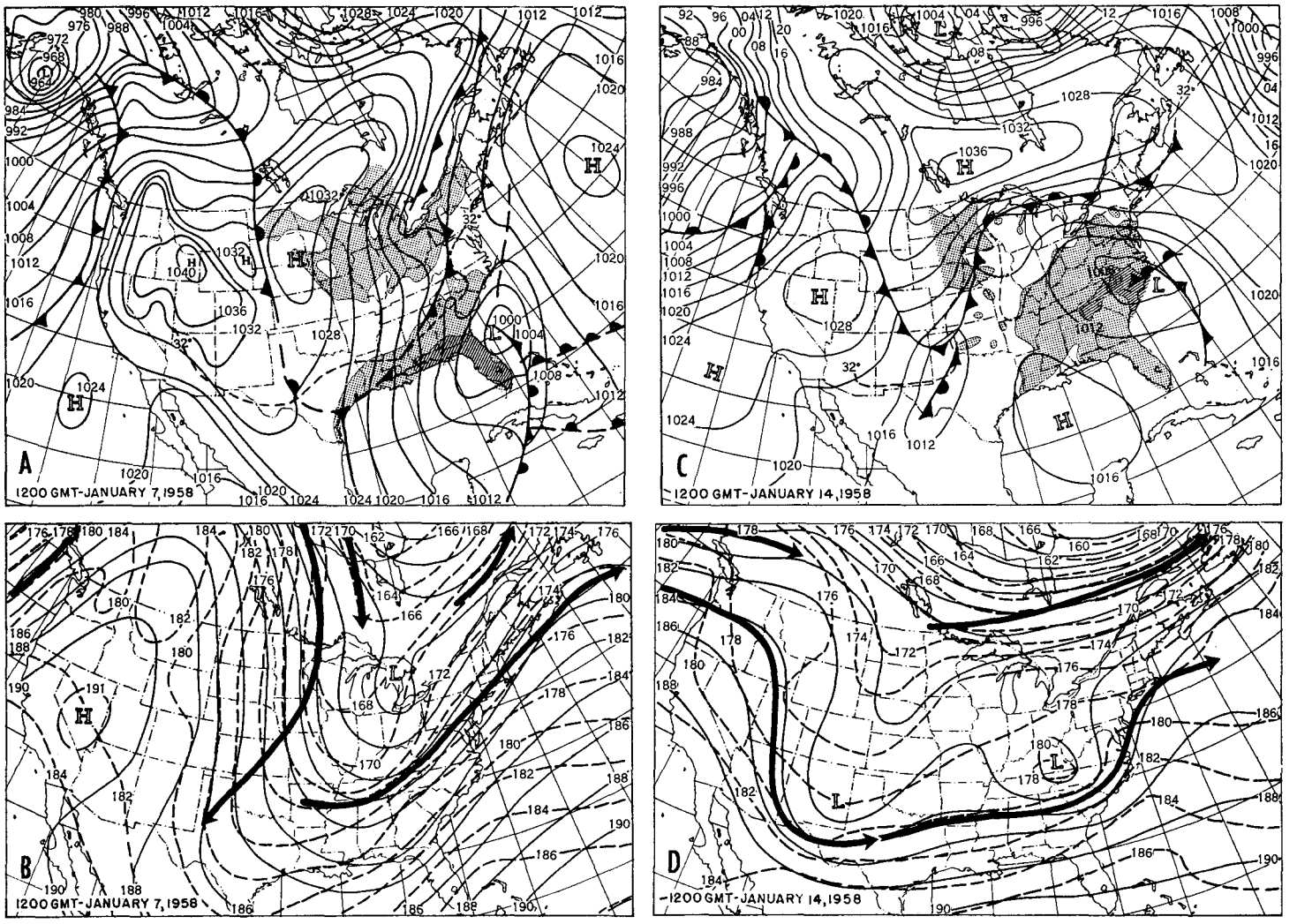

FIGURE 3.—Sea level synoptic charts (A) and (C) for 1200 GMT, January 7 and 14, 1958, respectively, and the corresponding 500-mb. charts (B) and (D), with 1000-500-mb. thickness lines (dashed) and 300-mb. jets. Areas of 1 inch or more of precipitation in the past 24 hours are shaded. Line labeled 32° shows southern limit of freezing temperature in previous 12 hours.

an extensive two-cell high pressure system over the western and northwestern United States. The western cell of this High remained stationary while the eastern cell moved south-southeastward into the Dakotas (fig. 3A). Another ridge from the western high cell extended southeastward over northern Mexico. At 500 mb. (fig. 3B), the western half of the country was covered by a high cell and ridge of great north-south amplitude with a strong southerly flow along the Pacific coast. The main jet swung up over southern Alaska, looped over far northwestern Canada and plunged south through the Plains States, crossing the central United States at about latitude 35° N., before swinging northeastward along the Atlantic coast.

By 1200 GMT January 7 (fig. 3A), a new Low had formed east of Jacksonville, Fla., with only a faint remnant of the parent Low remaining west of Tampa. The new Low reached normal intensity by this time, but its associated fronts over the ocean areas were still weak. The 500-mb. chart for 1200 GMT (fig. 3B), showed that the weak cyclonic vorticity center with Storm A had moved from Mississippi to southern Georgia, with the second cyclonic vorticity maximum over southern Louisiana. The Low near Sault Sainte Marie had moved southeastward over Lake Huron.

The surface trough over Labrador and Ontario was long and narrow (fig. 3A), with a slow southeast displacement. The Low over the eastern Great Lakes was filling as the Dakota High continued to move south-southeastward. At 500 mb. (fig. 3B), the flow pattern over the Western States remained the same, although the High over southern Utah had started weakening and the ridge over the Northwest Territories had begun to lose some of its amplitude.

At 0000 GMT January 14 (fig. 2C), a similar redevelopment took place with Storm B. While the parent Low was decreasing in intensity in northern Alabama, a new low center was forming in the vicinity of Charleston, S. C. This new Low reached normal intensity during the day (fig. 3C), while the original Low moved up the west side of the Appalachians and filled. At 500 mb. (fig. 2D), the low center with Storm B was just west of Nashville, Tenn., with a ridge to the east over the Atlantic coast. A flat trough covered the southern United States from Arizona east to the Atlantic, with a cyclonic vorticity maximum

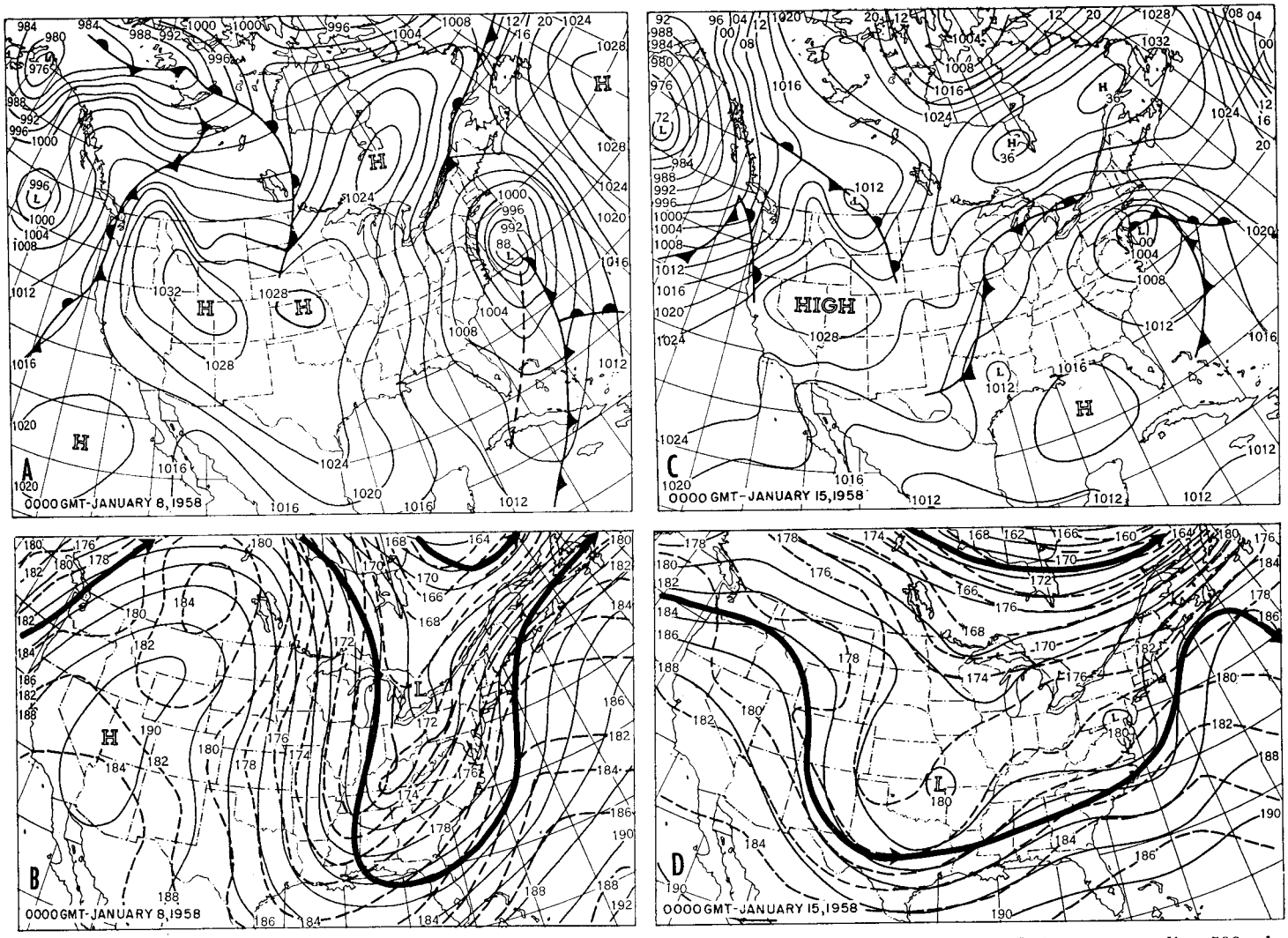

FIGURE 4.—Sea level synoptic charts (A) and (C) for 0000 GMT, January 8 and 15, 1958, respectively, and the corresponding 500-mb. charts (B) and (D) with 1000-500-mb. thickness lines (dashed) and 300-mb. jets.

over northern New Mexico, reflected on the surface by a weak Low over the Texas Panhandle.

On the surface a weak high cell was off the Atlantic coast northeast of Cape Hatteras (fig. 2C). An occlusion extended from southern Greenland to Newfoundland, then west as a stationary front roughly along the border of Canada and the United States. A high pressure cell dominated the Western States, while a broad, inverted trough covered the central United States. A High was over central Canada with a ridge to the east and southeast across New England. A small High was over the extreme western Gulf of Mexico. At 500 mb. (fig. 3D), the two centers of cyclonic vorticity moved eastward, with the New Mexico center moving more rapidly. A flat ridge, with a westerly flow, moved in over the Western States. The jet associated with this system extended from Utah south across Arizona and north-central Mexico, then east across the Southern States, with a slight northeast tilt off the Atlantic coast.

During the day (fig. 3C), the surface Low moved slowly northeastward, reaching southern Delaware by the end of the day. At the same time, the high pressure area over southeastern Canada shifted east and increased slightly. The weak trough to the southwest of Storm B persisted, with a small Low moving across Texas.

Surface and 500-mb. features with Storms A and B were relatively similar in the eastern part of the country, with the greatest dissimilarities over the Western States (figs. 2B, 3B). The synoptic charts were similar to the extent that there was a high cell northeast of Hatteras and another extensive High over the western United States with a general trough from Greenland to the Gulf of Mexico. One of the conspicuous differences in Storms A and B was in this east coast trough. With Storm B, there was actually a trough to the north and an inverted trough to the south of a ridge that extended easterly over New England from a High centered in central Canada north of the Dakotas. The east-northeasterly path of this High was also a divergence from the High in a similar position in association with Storm A. Although there was a small high cell in the extreme western Gulf of Mexico compared to the ridge over northern Mexico with Storm A, there was a decided difference in that there was a secondary trough between this High and the principal High over the Western States.

Once they redeveloped, the surface centers of Storms A and B followed similar paths, although at different speeds, and caused similar precipitation patterns along the coast. Behind Storm A at 500 mb. the very strong north-south

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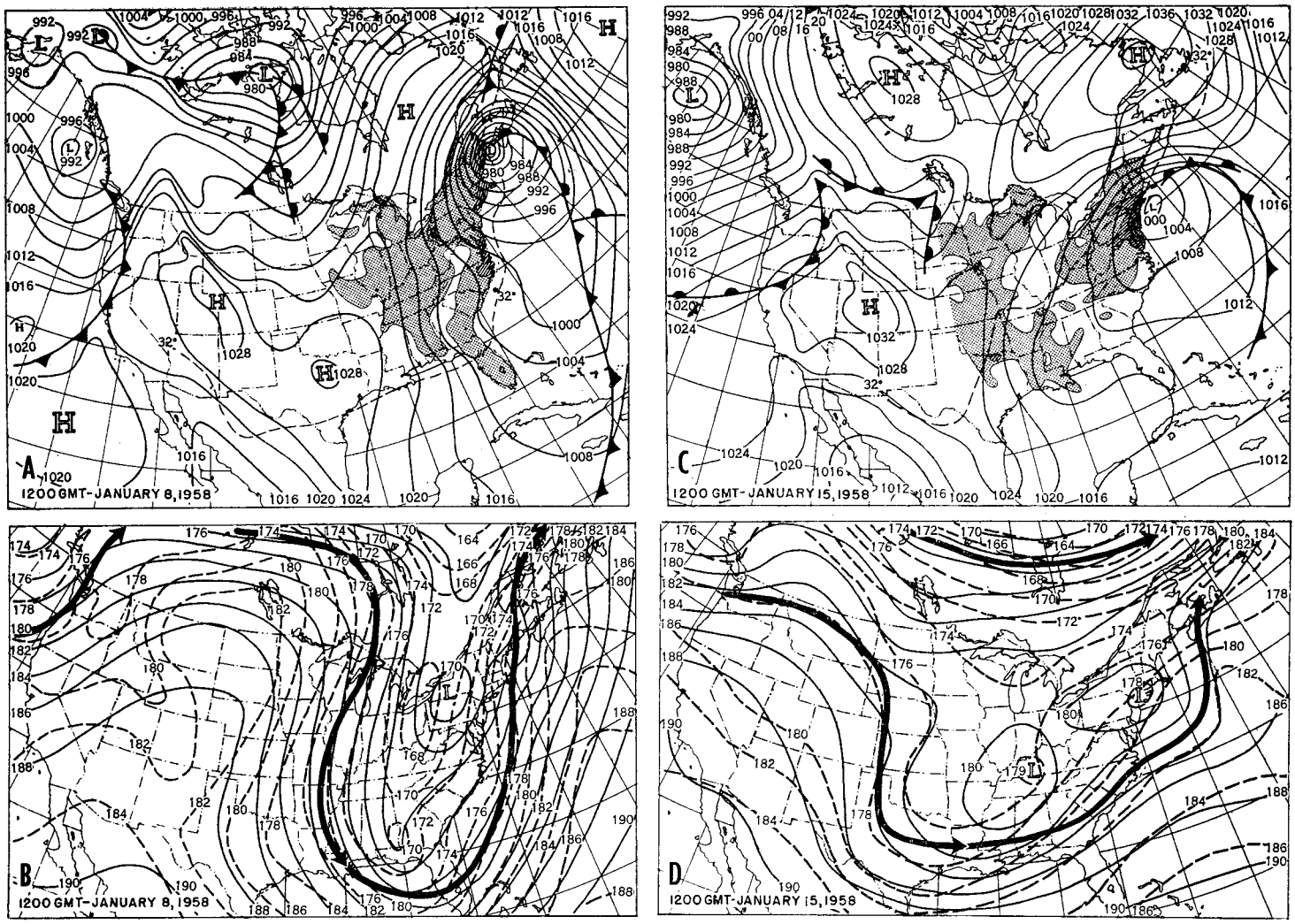

FIGURE 5.—Sea level synoptic charts (A) and (C) for 1200 GMT, January 8 and 15, 1958, respectively, and the corresponding 500-mb. charts (B) and (D) with 1000-500-mb. thickness lines (dashed) and 300-mb. jets. Areas of 1 inch or more of precipitation in the last 24 hours are shaded. Line labeled 32° shows southern limit of freezing temperature in previous 12 hours.

ridge caused a very strong northerly flow down the middle of the country. With Storm B, flow behind its low center was westerly, because of the second vorticity center over New Mexico. Storm A's cyclonic vorticity maximum was absorbed into the larger trough and was carried around it rapidly. Although Storm B's center was more definite it was imbedded in a less rapid flow and moved along its path at a more leisurely rate.

FIRST DAY WEATHER

On January 7, Storm A moved out of the Gulf, redeveloped near Jacksonville, and moved rapidly east of Cape Hatteras by 0000 GMT January 8. Rain associated with the center covered the extreme southeastern States, with amounts generally ½ to 1 inch. During the day, rain spread rapidly north and was over Nantucket and eastern Massachusetts after 1800 GMT. Snow over Virginia and inland North Carolina moved north to extend from Norfolk to the Canadian border by 1500 GMT. As rain changed to snow, sleet or freezing rain was reported in North Carolina and southern Virginia and in Providence, R. I. Snow amounts ranged from 1 to 4 inches, with heavier amounts in the immediate Atlantic coastal areas. Portland, Maine, and Hartford, Conn., reported 8 inches; Middletown, Conn., 9 inches; and Bridgeport, Conn., and Worcester, Mass., 10 inches. As the storm intensified off Cape Hatteras, winds reached gale strength over a wide area, with tides somewhat higher than usual causing minor flooding in the central Atlantic coastal area.

On January 14, the low center with Storm B was over northern Alabama. During the day it moved along the west side of the Appalachians and filled. Storm B redeveloped near Charleston, S. C., and slowly moved northward reaching southern Delaware by 0000 GMT, January 15. Precipitation with Storm B was predominantly rain, although freezing rain and sleet over Virginia early on January 14 moved up over West Virginia, Pennsylvania, and New York State during the day. Some freezing rain and sleet occurred also in southern New England and northern New Jersey. Rain spread north gradually, over the coastal areas and also along the western slopes of the Appalachians. By 0000 GMT January 15, the rain extended from eastern Kentucky to

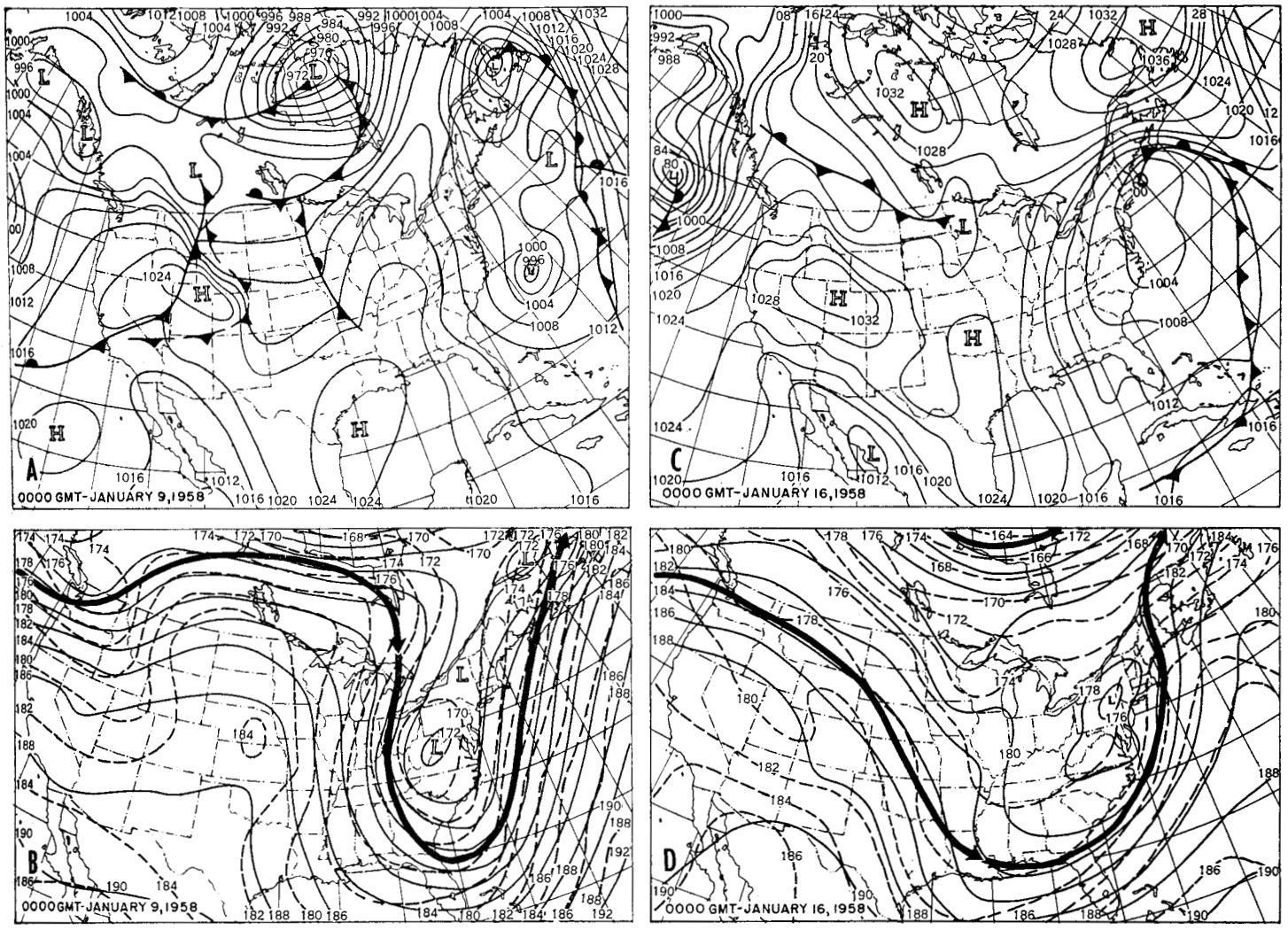

FIGURE 6.—Sea level synoptic charts (A) and (C) for 0000 GMT, January 9 and 16, 1958, respectively, and the corresponding 500-mb. charts (B) and (D) with 1000-500-mb. thickness lines (dashed) and 300-mb. jets.

Massachusetts and New York State. Storm B moved slowly, winds were not unusually strong, and precipitation amounts were not extremely large, generally ranging from ½ to 1 inch. Block Island reported 1.52 inches, Cape Hatteras 1.33 inches, and Norfolk, Va., 1.12 inches. Late in the day snow began to fall over south-central New England, with amounts ranging from 1.0 inch at Concord, N. H., and Portland, Maine, to 2.4 inches at Albany, N. Y., and 3.0 inches at Worcester, Mass.

At the end of the first day of their respective redevelopments, Storms A and B were both situated near the middle Atlantic coast—Storm A 120 miles east-northeast of Cape Hatteras and Storm B over southern Delaware. Their paths were drawing closer together—although Storm A had redeveloped near Jacksonville and Storm B near Charleston, S. C. Storm A had a more definite character and more intense circulation throughout these early stages but Storm B gradually took on a definite circulation, though not reaching the same intensity as Storm A. Precipitation patterns were similar in area. Storm A produced larger amounts of rain and snow in the north in its early stages because of its rapid movement, intensification, and overrunning. Both Storms A and B caused heavy rain and snow over southern New England, although Storm A's actual amounts were larger than Storm B's. Storm A caused heavy snow along the mid-Atlantic coast, which Storm B did not.

SECOND DAY FEATURES

On January 8, at 0000 GMT (fig. 4A), Storm A was 120 miles east-northeast of Cape Hatteras. Its central pressure was 980 mb., reflecting a 12-hour deepening of 16 mb. This central pressure, lower than two standard deviations from normal, classed the Low as very intense. The deep cold trough associated with the Low at 500 mb. (fig. 4B), was oriented northeast-southwest from Lake Erie to the western Gulf, with a center north of Toronto, Ontario. There was one center of cyclonic vorticity over northern West Virginia and another, more pronounced, over northern Alabama.

During the day, Storm A traveled northeastward at 40 knots and continued to deepen rapidly. At 0650 GMT, as it passed near Nantucket, surface pressure there dropped to 960 mb., a new record for the lowest January surface pressure. This was more than 5 standard deviations below normal for this latitude. James [2] classed Lows with central pressure more than 2 standard deviations below normal as very intense. It is interesting to

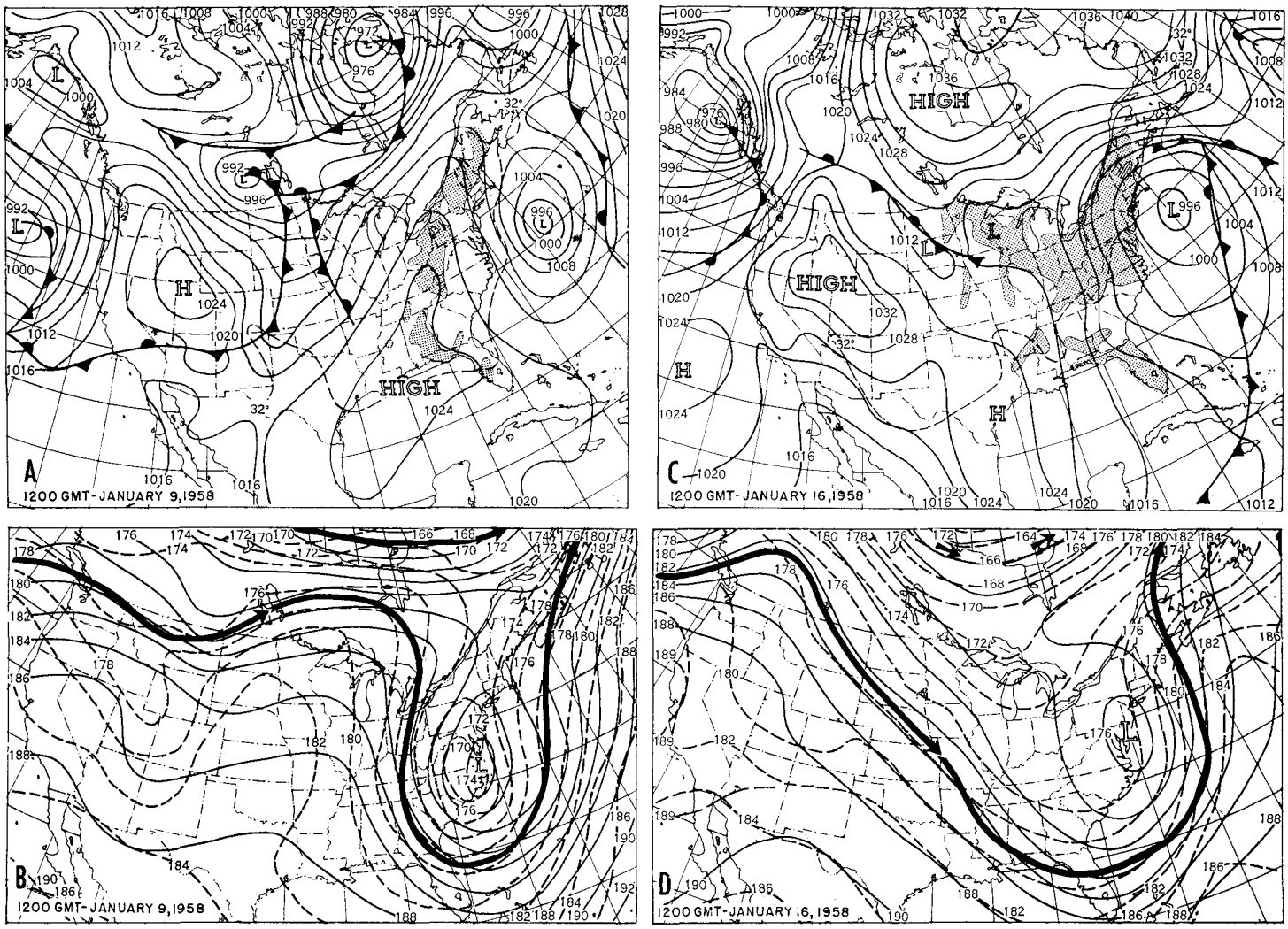

FIGURE 7.—Sea level synoptic charts (A) and (C) for 1200 GMT, January 9 and 16, 1958, respectively, and the corresponding 500-mb. charts (B) and (D) with 1000-500-mb. thickness lines (dashed) and 300-mb. jets. Areas of 1 inch or more of precipitation in the last 24 hours are shaded. Line labeled 32° shows southern limit of freezing temperature in previous 12 hours.

note that very intense Lows occur 1 time in 40. This is another indication of the intensity reached by Storm A.

At 500 mb., the cyclonic vorticity center in West Virginia moved northeastward to northern Maine (fig. 5B), and the second dropped sharply southward from Alabama to the vicinity of Albany, Ga. (fig. 5B), then moved northeastward and at day's end was off the coast of South Carolina. A residual Low, not noticeably reflected in the flat gradient at the surface, was centered near Syracuse, N. Y., and later filled (fig. 6B) as the Low formed over western Maryland.

In the 24-hour period preceding the greatest intensity of Storm A, the cold trough at 500 mb. underwent dramatic deepening (figs. 3B and 5B). The main jet dipped sharply south over the Mississippi River and across the northern Gulf. Cold air continued to be advected southward rapidly. Over most of the extreme southeastern States, 24-hour 500-mb. height falls ranged from 600 to 800 feet, with falls in excess of 800 feet at Jacksonville and Eglin AFB, Fla. Correspondingly, temperatures at the 500-mb. level dropped 10 to 12 C.° in 24 hours, with a 14° drop at Patrick AFB, Fla., and a 15° drop at Jacksonville. Ahead of the trough, the jet remained in a generally southwest-northeast direction along the Atlantic coast, Maritime Provinces, and Newfoundland, and carried warm air well to the northeast.

As Storm A moved away from the Cape Cod area, it began filling (fig. 5A), and at 0000 GMT January 9 (fig. 6A), had a central pressure of 986 mb. As it filled, the 500-mb. Low lost its closed circulation and became absorbed into the trough, moving by day's end, to the Gulf of Saint Lawrence. As Storm A moved northeastward, a surface trough remained to the southwest behind it and a second, quasi-stationary, Low formed 250 miles southeast of Cape Hatteras. During this time, the low center at 500 mb. traveled from eastern Tennessee to western Maryland, deepening steadily until it became the dominant 500-mb. Low over the eastern United States.

At the surface, while Storm A traveled through the Atlantic coastal waters the Atlantic high cell south of Gander, Newfoundland, moved slowly eastward with a 4-mb. increase in its central pressure. The weak ridge associated with this High at 500 mb. moved eastward also, and weakened slightly. The large surface High persisted

over the Northwestern States while the ridge of high pressure associated with it aloft weakened, flattened, and moved from Utah (fig. 4B) to the Plains States (fig. 5B). The main jet (fig. 4B) at the beginning of the day, crossed the extreme northwestern portion of the United States, then swung well to the north over central Canada before dipping south. As the ridge weakened during the day, the jet remained over Canada but took on an east-west orientation.

A sharp ridge built up to the northeast over central Ontario, near Moosonee. This was reflected at the surface by the quick southward movement of the Kansas High to Texas, and the persistence of a long, narrow ridge across south-central Canada east to Goose Bay, Labrador. Behind the surface High in the west, the occlusion weakened and drifted slowly eastward while at 500 mb. a short-wave trough entered the Northwest (fig. 6B). A very intense low center over Hudson Bay moved eastward as its upper trough moved rapidly across the top of the 500-mb. ridge. A surface warm front associated with the Hudson Bay Low moved eastward across North Dakota.

On January 15, at 0000 GMT (fig. 4C), Storm B was about 20 miles southeast of Dover, Del. A central pressure of 996 mb. made it a normal to intense Low for this latitude, and there was very little change in its intensity through the day. At 500 mb. (fig. 4D), the low center associated with Storm B was about 25 miles west of Philadelphia. During the day it moved slowly northward while the surface Low traveled northeastward at 15 knots to reach Boston by the end of the day. Flow ahead of the storm was easterly and increased in intensity as the center moved northward. The jet associated with this system crossed Texas and the South, then swung northeastward along the Atlantic coastline.

A weak trough remained to the south of Storm B, between the Atlantic coast and Bermuda. Another trough, though less pronounced, extended southwest to a small low center over eastern Texas (fig. 4C). These troughs caused a northeasterly return circulation over the northeastern United States (fig. 5C). The small eastern Texas Low was in conjunction with a 500-mb. Low centered near Joplin, Mo. (fig. 4D). During the day, as the surface Low traveled east to become absorbed into the larger Atlantic coast trough, the upper Low moved very rapidly eastward (fig. 5D), to join with the Low associated with Storm B. This double Low system at the 500-mb. level caused a wider trough aloft, with a flatter, more westerly flow across the Southern States. The 500-mb. ridge over the Northwest (fig. 4D), was also relatively flat, so the circulation pattern did not produce any marked warm or cold advection.

The weak front across the North Central States and the Plains States dissipated during the day (fig. 5C). The surface ridge in the Atlantic east of Storm B persisted, as the Moosonee High moved eastward off the coast of Labrador and Newfoundland, with a 5-mb. increase in pressure. At 500-mb., the Atlantic ridge moved very slowly eastward, with no appreciable change in intensity. As the Moosonee High moved eastward a strong westerly circulation was evident over southeastern Canada at the 500-mb. level (fig. 5D).

The surface high cell over northern Utah drifted slowly southeastward (fig. 5C) as an occlusion moved in behind it and frontolyzed. A ridge to the east of this center built up during the day over an area from Texas north to Nebraska, and a lee trough formed over western Texas and eastern New Mexico. At 500 mb. (figs. 4D, 5D), a moderate ridge persisted over the Northwest throughout January 15, although a very weak short wave, associated with the weak trough and warm front over Montana and North Dakota, moved in over the Northwestern States. The main jet was westerly across Washington and Montana (fig. 4D).

Both storms traveled along the same paths on their respective second days, although Storm A was much more intense and moved more rapidly. Both storms had residual low centers form in the troughs behind them. Although there were quite a few similarities in the surface patterns of Storms A and B, at the 500-mb. level, the greatest similarity was in the positions and tracks of the Lows associated with the main surface centers of the two storms.

At the surface, ridges of high pressure set in over the central United States in both cases, although with Storm B the ridging process was slowed down while the small eastern Texas Low traveled across the Southern States. The 500-mb. flow over the ridge with Storm A was strong and northerly; with Storm B, the flow was westerly of moderate strength, and gradually shifted around to become more northwesterly. Both of these ridges extended into Canada, but with Storm B the ridge had an eastward elongation. The High centered off the Labrador coast with Storm B was more intense and became a formidable block.

Surface pressure was generally high over the Northwest with associated ridges aloft over the Western States. With Storm A the ridge was a large-amplitude ridge that flattened during the day, while Storm B had a flatter ridge over the western half of the country throughout the day.

The great amplitude of the 500-mb. ridge and trough with Storm A produced very strong advection of cold air behind the trough and warm air ahead, contributing importantly to its very dramatic deepening. With Storm B, the amplitude of the ridge and trough at 500 mb. was less accentuated and no pronounced warm or cold advection was associated with the system.

SECOND DAY WEATHER

On January 8, as Storm A swept northward, rain was general along the coast, with snow over North Carolina and Virginia. During the day, snow spread gradually over northern Virginia, eastern Maryland, Delaware, and New Jersey reaching later in the day over Pennsylvania, New York State, and New England. Sleet and freezing rain occurred spottily in a line roughly through Connect-

icut, northern Pennsylvania, central New York State, and even into Ohio. Snow occurred over the Appalachians, Kentucky, Tennessee, and well into central Alabama. Snow amounts along the immediate coastal area were heavy, with amounts over 12 inches in eastern Maryland, and 8 to 15 inches along the New Jersey coast. Over New England, snow amounts had accumulated 4 to 12 inches, and along a 30- to 50-mile-wide belt from north-central Maine to the Connecticut coast accumulations totaled 12 to 20 inches. Portland, Maine, and Bridgeport and Hartford, Conn., reported 11.0 inches of snow; Middletown, Conn., 12.0 inches; Worcester, Mass., 13.0 inches; and Concord, N. H., 14.5 inches. Snow was reported at several locations in Florida and Georgia, although it melted as it fell or left just a small amount on the ground. Heavy amounts of rain fell over Cape Cod, Massachusetts' south shore, and the eastern Long Island-Nantucket area. Nantucket reported 1.56 inches of rain with the storm, Block Island 2.31 inches, and the Cape Cod area amounts up to 4.50 inches. Storm A was accompanied by violent winds of hurricane force near its center as it passed over the Nantucket and Cape Cod areas. Considerable damage was caused by the winds and resulting higher than normal tides.

On January 15, as Storm B moved slowly north, it was preceded by general rains covering southern New England, New York State, Pennsylvania, and from West Virginia east to the Atlantic coast. Rain amounts ranged from half an inch to 1 to 3 inches. Providence reported .91 inch and Boston 1.79 inches. Freezing rain and sleet occurred along Lake Erie and Lake Ontario and in scattered areas in New York and Connecticut. Snow was falling over southern Vermont and New Hampshire and the southwestern corner of Maine. During the day, snow spread gradually over New England. Snow amounts were generally 1 to 3 inches, with 5 inches reported at Portland, Maine, 6 inches at Burlington, Vt., 7 inches at Albany, N. Y., and 9 inches at Caribou, Maine. As Storm B moved over the New England coastal area its center was accompanied by winds of gale force—the fastest mile of wind at Nantucket was 52 m. p. h. from the east. As colder air flowed down behind the storm, precipitation over Ohio, Pennsylvania, and West Virginia changed to snow. At the same time, snow and some areas of freezing precipitation spread into Kentucky and Tennessee.

Although both Storms A and B had marked similarities in their paths, precipitation patterns, and precipitation amounts, there was some difference in their intensity. Storm A produced heavy amounts of snow and rain along the coastal areas and as it reached its lowest pressure produced hurricane winds near its center. Its movement was very rapid and weather associated with it was severe, in some areas causing considerable damage. Precipitation associated with it reached from central Alabama across the whole tier of Eastern States. Storm B produced large amounts of snow and rain also, but its progress was slower, and its precipitation, though widespread, not generally of such large extent or amounts as those of Storm A. Winds reached gale strength with Storm B, but did not cause damage as serious as that of Storm A. Storm B's slower movement was another cause of its large precipitation amounts.

THIRD DAY FEATURES

The phase of development on the third day represented the concluding differences in the storms. By 0000 GMT January 9 (fig. 6A) Storm A had filled to 986 mb., which classed it an intense Low, as it raced northeastward across the Atlantic Ocean. At 500 mb. (fig. 6B) the Low was north of Nova Scotia, a part of the extensive trough from Labrador southwest to the strong Low over western Maryland. During the day (fig. 7B), this strong Low center moved to the southeast. A rather straight southwesterly flow was ahead of this trough while the broad area of northerly winds to the west remained. The Nova Scotia Low was reflected in the very intense residual Low that had developed east of Cape Hatteras (fig. 6A). This Low persisted, and as it slowly filled, moved northeastward along the track Storm A had followed (fig. 7A).

The High in the Atlantic gave way slowly to the east and the ridge pushing into the western Gulf of Mexico amalgamated with the high cell that had traveled south from Canada to form a 1027-mb. High in the western Gulf (fig. 7A). This regime continued throughout the third day, with a large easterly-moving Low in central Canada and its companion wide trough lagging to the lee of the Rockies. The Western States remained under the influence of a large stationary high cell over northern Utah.

As Storm A's 500-mb. Low moved out and the residual Low took over, the marked cold air advection decreased. To the west, a 500-mb. short-wave trough associated with the surface trough over the Plains States, moved in along the westerly flow (fig. 7B). The main jet dipped down over Washington and Montana in association with this short-wave trough, then swung east across south-central Canada, south around the residual Low, and then northeast over the Atlantic and Newfoundland.

At 0000 GMT January 16 (fig. 6C) the blocking High had established itself well along southern Canada and Storm B almost came to a standstill. Minor new developments to the south of the Low moved up to the block and were absorbed into Storm B's original Low (fig. 7C). Instead of filling on the third day as Storm A did, Storm B continued to intensify (fig. 7C) reaching very intense status near the end of the period. However, Storm B never reached an intensity as great as that of Storm A.

At 500 mb. (fig. 6D) a marked sharp ridge extended along longitude 60° W., from latitude 35° N. to the Maritime Provinces. The two centers of cyclonic vorticity in the east consolidated (fig. 7D) and moved eastward. A moderate northwesterly flow persisted behind this eastern trough during the day, as a minor trough crossed the Midwest.

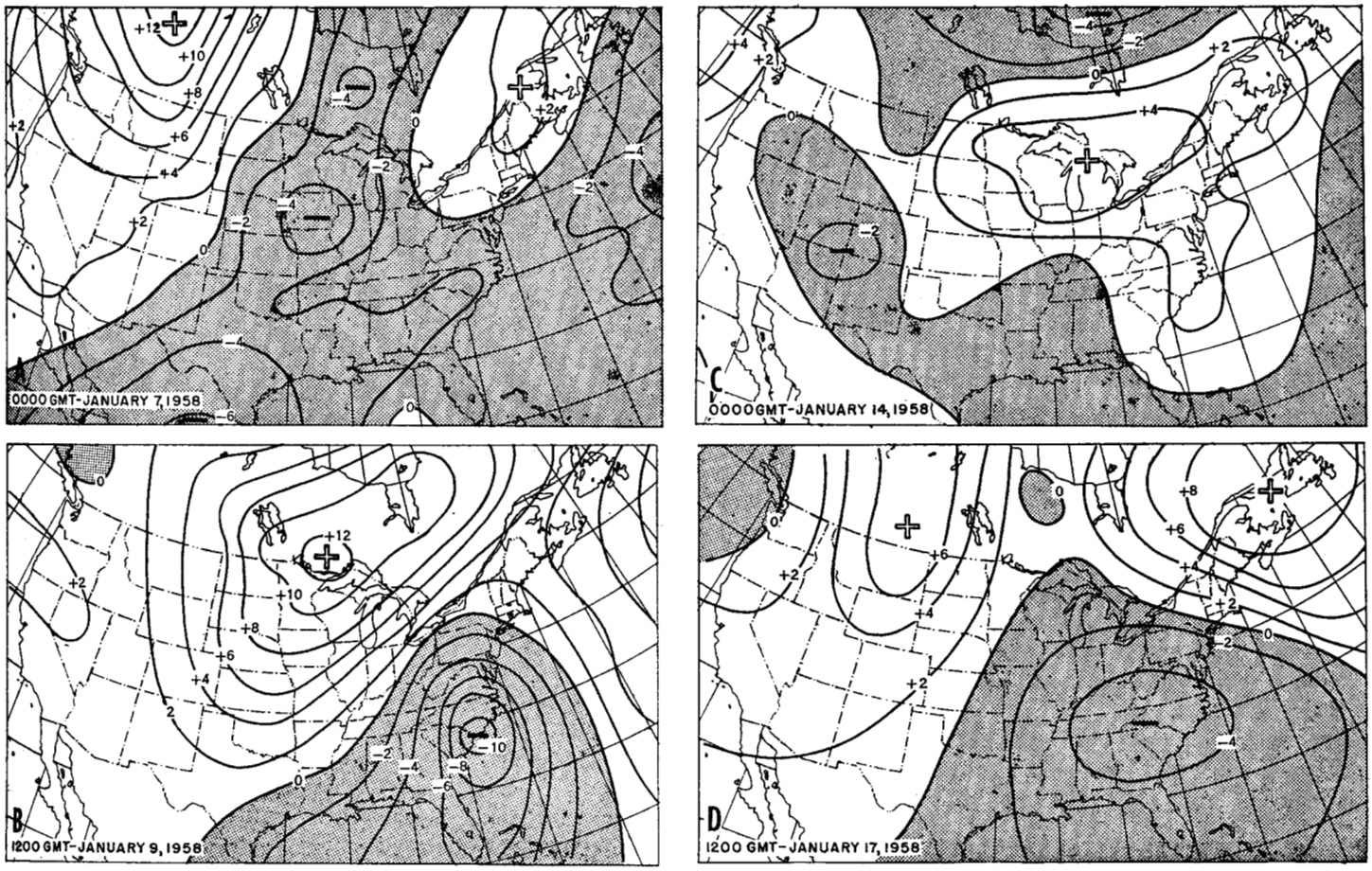

FIGURE 8.—Departure from normal of the 1000-500-mb. thickness, (A) 0000 GMT, January 7, (B) 1200 GMT, January 9, (C) 0000 GMT, January 14, and (D) 1200 GMT, January 17, 1958.

At the surface at day's end (fig. 7C) Storm B had begun to retrograde to the northwest. A northerly flow covered the Eastern States, with a stationary High over the Far West and a second High over Texas. A weak, complex low pressure area was over Minnesota and the Dakotas.

On the third day, Storm A moved away to the northeast while Storm B was blocked by the high pressure cell in the Labrador area. Troughs persisted to the south behind both storms, causing cold northerly flow over the Eastern States. In both cases stationary Highs dominated the West with high pressure areas over Texas and the western Gulf and low pressure areas over the Plains States.

THIRD DAY WEATHER

On January 9, at 0000 GMT (fig. 6A), Storm A had moved over Newfoundland. A second small low center, of normal intensity (999 mb.), was located 5° of longitude east of Cape Hatteras. The strong northerly circulation had set in over the Eastern States. Snow flurries were general over New York State, upper New England, to the lee of Lake Erie, and along the Appalachians. During the day, Storm A moved rapidly eastward and the secondary Low drifted very slowly to the east. Temperatures in the South and East which were under the influence of cold air for several days, dropped well below normal. Temperatures in north and central Florida on January 9 ranged from 18° to 29° F. and in the Everglades from 26° to 30° away from the lake and 30° to 35° near the lake. Temperatures along the east coast were above freezing, but inland, freezing temperatures and frost were reported. The cold weather caused damage to citrus fruit, especially in the north, and heavy damage to truck crops and young plants. Some minimum temperatures in Florida on January 9 were: Tampa 31° F., Lakeland 28°, Orlando 27°, Apalachicola 26°, and Tallahassee 23°.

Elsewhere in the South, temperatures ranged from near zero (5° F. at Farmerville, La.) through the teens and twenties (Greensboro, N. C., and Rome, Ga., 10° F.; Norfolk, Atlanta, and Birmingham 17°; Shreveport and Baton Rouge 23°; and New Orleans, 26°). Although this cold spell set no great number of extreme minimums, the cold air covered a broad area and persisted for 2 to 4 days, where usually such cold spells move quickly off after 1 or 2 days.

On January 16 (fig. 7C), as Storm B remained off Cape Cod, blocked by the large High over Labrador, a trough extended to the southwest along the Atlantic coast. Snow fell over Vermont, New Hampshire, western Maine, New York State, and Pennsylvania. Rain occurred in the coastal areas of New England and southeastern Maine. Snow flurries fell along the Appalachians

as far south as Asheville, and rain fell along the Middle Atlantic coastal area and over central North Carolina.

As a result of the blocking and east coast trough, flow over the Eastern States was northeasterly, with the strong northerly flow not setting in until January 17. Temperatures in the South did not reach the low values experienced with Storm A. In the mountains of New York State, snow amounts of 1.5 to 2 feet were reported, with 8 to 15 inches reported over New England. Albany, on January 16, had an accumulation of 15.4 inches, Caribou 10.2 inches, and Burlington 8.9 inches. Two inches of new snow fell at Newark on the same day.

Both Storm A and Storm B had troughs of low pressure remaining behind them. A new Low generated off the middle Atlantic coast as Storm A moved away. Storm B was blocked and remained off the New England coast, closer in than the Low left by Storm A. As a result, Storm B caused protracted precipitation over New England and New York State, with heavy snowfall amounts in the mountainous areas. Along the coast and to the south, moderate amounts of rain fell. Weather behind Storm A ended as soon as the main storm moved away, but extremely cold air rushed south rapidly behind the center. Storm B remained at or near normal intensity but cold advection was delayed approximately 24 hours behind it, with freezing temperatures again affecting Florida on January 17 and 18.

4. DEPARTURE FROM NORMAL 1000-500-MB. THICKNESS

In objective evaluations of the relative intensities of storms, the thermal field is of significance. For the consideration of this concept to complement the previous impressions from the classification of intensities according to James [2], the 1000-500-mb. thickness departures from normal were examined (fig. 8). Conditions at the time of redevelopment are shown by the 0000 GMT charts (figs. 8A and C), and during the concluding stages by the last day's 1200 GMT charts (figs. 8B and D) of each of these storms. At the time of redevelopment, both storms had reached normal intensity, but Storm A obviously had the greater potential according to the departure from normal charts. Although there was a very slight above normal thermal field ahead of Storm A, the below normal area to the rear denoted a strong thermal gradient in the redevelopment area. The above normal area ahead of Storm B was more prominent in the proximity of redevelopment and gave a clue to blocking action that became of more consequence later.

The departures from normal for January 16 and 17 being similar, the chart for the 17th is shown to emphasize the blocking. A surprisingly comparable appearance of blocking conditions during the final stages of these two storms comes from an objective assessment of figures 8B and D. This assumes that the above normal area over southeastern Canada indicates a warm blocking ridge. However, rapid movement took Storm A far seaward from the area by that time. High pressures did build behind Storm A and ahead of a secondary Low after January 9, and the period of this discussion.

5. CONCLUSION

Although we have classed these storms as Texas Lows and have found analogous characteristics, the disparate developments were distinct. It is not evident that either one was an average situation.

The precipitation patterns were similar, but with Storm A they were the result of intensity and with Storm B the result of duration.

Intensity of a Low can be classed according to its central pressure compared to the mean central pressure of other Lows at the same latitude, but the characteristics of associated pressure systems also have an important bearing on its classification.

Because normal charts are prepared from a large amount of data, they reflect differences as strongly as does a study such as the one by James [2]. The 1000-500-mb. thickness departure from normal chart does not indicate the intensity of Lows, but it gives evidence of the intensity of thermal fields. In the cases presented here, the more pronounced thermal gradient, as indicated by the greater magnitude of the departure from normal, appears with the more intense storm.

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